Application of a Localised Direct Conditioning Mineral Resource Modelling Technique for Medium and Long-term Mine Planning of Underground Mining Operations

August 2015

Winfred Assibey-Bonsu
Charles Muller
Hendrik Pretorius

Gold Fields

CJM Consulting

Content

- Introduction
- Background
- LDC Metodology
- LDC as applied by South Deep Gold Mine
- Conclusions

CJM CONSULTING

Introduction

- For new mining projects or for medium to long-term areas of existing mines, drilling data are on a relatively large grid.
- Direct estimates for SMU and also of much larger block units will then be smoothed due to the information effect and the high error variance of the estimate.
- During actual mining, selection will be based on the estimated grades of selective mining units utilising the final close-spaced data grid

CJM CONSULTING

Introduction

- Various post-processing techniques have been proposed to correct for the smoothing effect where data is widely spaced and sparse:
  - Spectral-processor(Journel et all 2000)
  - Conditional simulations
  - Indirect post-processing (Assibey-Bonsu and Krige 1999, Marcotte and David 1985)
  - Uniform Conditioning and assumed lognormal distribution of SMU’s within large planning blocks.
- This paper presents a direct approach technique for deriving recoverable resources (Localised Direct Conditioning LDC), designed to correct smoothing effects and also to provide support corrections, developed within the Gold Fields Group.

CJM CONSULTING

Background

- The LDC methodology has been developed for Gold Fields South Deep underground mine, where stope designs using probability recoverable estimates on indirect basis, have practical limitations.
- South Deep mines the Upper Elsburgs which comprise multiple stacked reef horizons that form part of an easterly-divergent clastic wedge (120-130m thick)
- Individual reefs can be as thick as 15m, therefore 1m composite lengths are used vs full composite.
- Geozones – reef characteristics, grade relationships are used to delineate geozones for estimation.

CJM CONSULTING

Background

- Both Ordinary (OK) and Simple Kriging (SK) techniques are applied in developing SMU blocks (30x30x1) estimation grade models.
- SK panel grades are used for the post-processing of recoverable resources which are used for mine planning – higher kriging efficiencies observed for SK panel estimates.
- Theoretically, the slope of regression of an SK estimate is 1. In this regard, the SK panel estimates are conditionally unbiased.
- The SK process uses a local or global mean depending on availability of data.

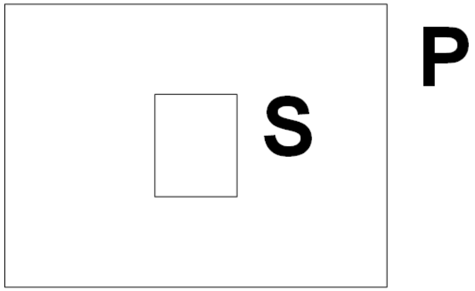
CJM CONSULTING

Background

- In providing the mean value, historical mined out information is taken into account.
- It is critical that the SK input means are analysed for robustness.
- Mine planning requires a single block value and therefore development of LDC rather than the indirect method which provide a proportion above a cut-off grade.

CJM CONSULTING

LDC Methodology - Definitions



S = Selective mining unit (SMU) of interest.
P = Entire population or global area being estimated.
BV_s = Variance of 'actual' SMUs in P (the theoretical dispersion variance of S in P).
σ^2_{se1}, σ^2_{se2} = Error variances of conditionally unbiased estimates at exploration (or for long-term estimates) and final production stages for SMU's respectively.

Dispersion variances of conditionally unbiased estimates for direct SMU's

$= BV_s - \sigma^2_{se1}$	(at exploration stage)	[1]
$= BV_s - \sigma^2_{se2}$	(at final production stage)	[2]

Dispersion variance at exploration stage from equation 1 has to be adjusted up to that of the final production stage, i.e. equation 2 by:

$$BV_s - \sigma^2_{se2} - (BV_s - \sigma^2_{se1})$$
$$= \sigma^2_{se1} - \sigma^2_{se2} \qquad [3]$$

LDC Methodology

- LDC estimates are derived from initial direct smooth kriged estimates.
- The initial *Direct Conditioning* (DC) is derived by super-imposing on the kriged estimate for each SMU block, a simulated lognormal distribution of expected 'actual' values with a variance equal to the difference in variability between the smoothed and 'actual' grades (equation 3).
- The simulated probability distributions have been derived using log-normal distribution of SMUs based on observed lognormal distribution of the point data (see Krige 2003)
- The end result is an estimated unsmoothed grade-tonnage curve to replace the smoothed kriged equivalent.

CJM CONSULTING

LDC Methodology

- The LDC methodology referred to in this paper extends the Localised UC technique as proposed by Abzalov (2006).
- Abzalov uses the grade-tonnage functions from the large panel *indirect* estimates (derived from UC) and then decomposes the panel-specific grade-tonnage data into a suite of individual SMU grades within their respective panels.
- Abzalov suggested that the individual parcel grades of the SMUs derived from the decomposed UC approach be assigned to the SMU size blocks within the respective panels based on a ranking of direct SMU grade estimates.

CJM CONSULTING

LDC Technique as Applied by South Deep

- Derive Simple Kriging (SK) estimates of SMUs.
- Estimate the local conditional probability distribution (lcpd) of non-smoothed grade estimates.
  - The lcpd uses each smoothed SMU kriged estimate as the mean of the distribution and associated variance parameter that is equal to that expected for the ‘actual’ SMU grades. (after correcting for expected final production information effect)
  - This process provides probability distributions of exceeding cut-off and grade above cut-off values for respective SMUs (grade tonnage curve per SMU).

LDC Technique as Applied by South Deep

- Agglomerate individual SMU grade-tonnage results into a ‘panel’ (in this case 120mx120m).
- Decompose the resultant ‘panel’ grade-tonnage function above to yield unsmoothed SMU grades; the linkage of these grades to SMU is obtained through ranking of the original smooth SMU estimates.

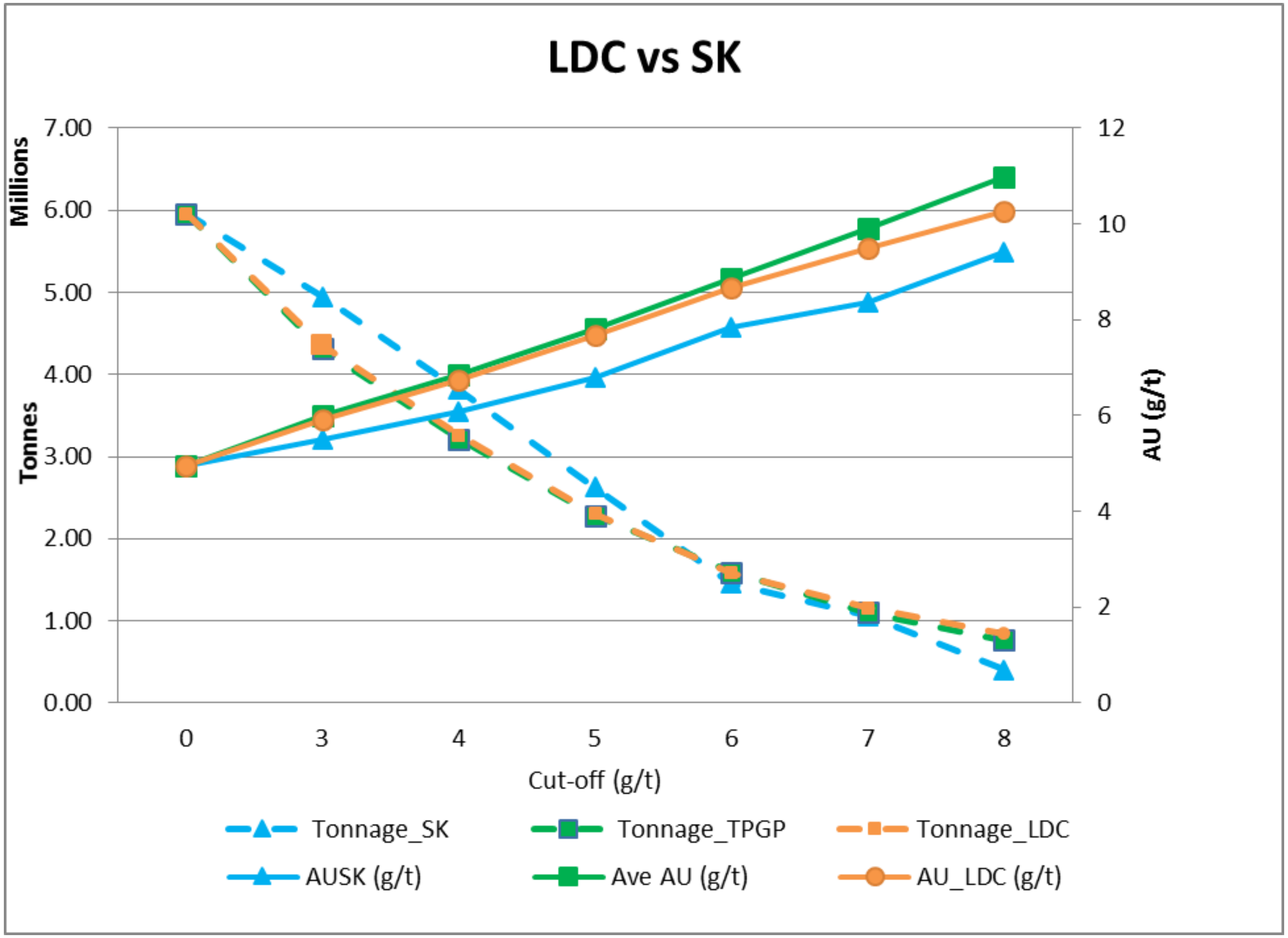
CJM CONSULTING

LDC Technique as Applied by South Deep

- The direct post-processing techniques effectively provides the average proportion of ore and corresponding grade, which can be expected to be selected for mining when grade control data becomes available.
- These unsmooth post-processed estimates can then be used in medium, as well as life of mine plan or for feasibility studies.

CJM CONSULTING

Comparison between Initial SK and LDC



CJM CONSULTING

Reconciliation of LDC Estimates

- LDC recoverable estimates compared with follow-up Grade Control estimate

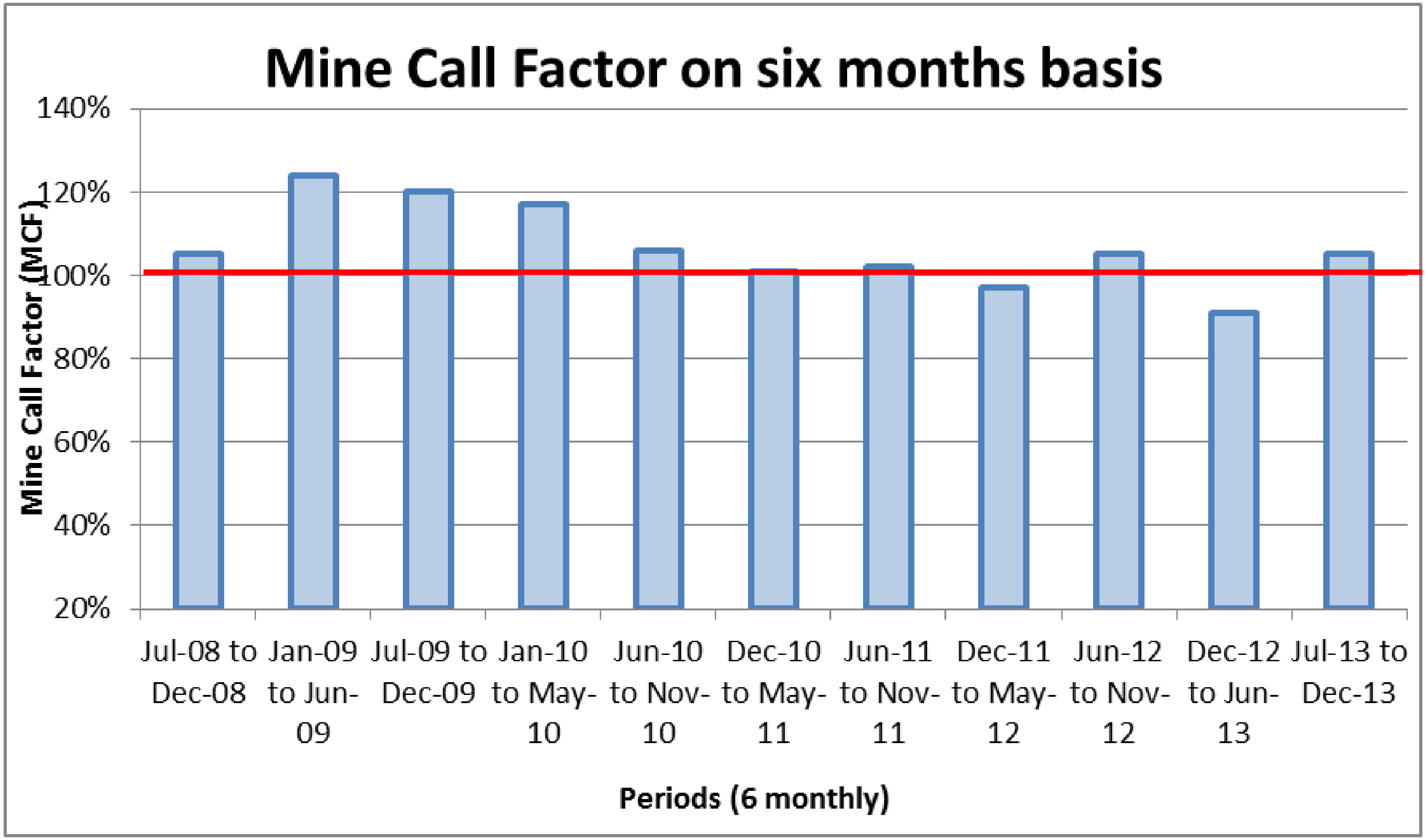
Cut-off (g/t)	Mean grade above cut-off (g/t)		Proportion above cut-off (%)	
	LDC	Grade Control	LDC	Grade Control
0	16.89	17.85	100.0%	100.0%
3	17.39	17.86	97.14%	99.95%
4	17.39	17.86	97.14%	99.95%
5	17.43	17.86	96.80%	99.95%
6	17.62	17.86	95.28%	99.95%
7	17.78	17.91	93.94%	99.58%
8	17.98	17.96	92.16%	99.08%

CJM CONSULTING

Analysis of MCF following the Introduction of LDC

- Although there are several direct and indirect production and modifying factors which affect the MCF, the paper presents the observed MCF changes pre and post LDC
- The observed improved correlation of MCF following LDC does not necessary provide conclusive evidence, however the good LDC and GC reconciliations tend to support this.

CJM CONSULTING



CJM CONSULTING

Conclusions

- Reconciliations to date at South Deep show encouraging results following the introduction of LDC.
- It is important that the mine strives to maintain and keep abreast of the necessary grade control programmes, which will improve local scale estimation, as LDC is aimed at medium to long term recoverable resource estimates.
- Though there are other indirect production and modifying factors affecting the MCF, the general observed improved MCF since the introduction of LDC for a period of more than three years could be attributed partly to the improved LDC estimates

CJM CONSULTING

END

CJM CONSULTING